Long-term photocapacitance decay behavior in undoped GaN

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Gallium nitride has recently received much attention in varieties of device applications, such as high-temperature transistors,[1] blue and green light-emitting diodes and violet laser diodes, because its superior material properties including wide direct bandgap, high breakdown electric field, high thermal conductivity as well as high thermal stability. However, as compared to GaAs and InP the GaN film usually possesses relatively poor film quality in term of dislocations. With such a high density of threading dislocations ($10^8 cm^{-2}$), it is hardly believed at the beginning that high performance of optoelectronic devices can be realized without difficult by the use of this type of material. In this letter, we examine the physical properties of GaN film by observing for the first time the long-term photocapacitance decay behavior in undoped GaN. Our results showed that the steady state value of transient photocapacitance decays logarithmically at room temperature, which, we believe, is correlated closely to the recombination at dislocations.

The sample employed in this study is the same undoped GaN as previous revealed.[2] For measurements of photocapacitance, the Schottky diode was illuminated by ~60 W tungsten lamp for 5 minutes at zero bias voltage. The sample was then subjected to the transient capacitance measurement at 297.5K using a HP4194 impedance analyzer at different probe time *t* varied from 1 min. to 12 hours. For each measurement, a reverse bias of –1V of square trigger with duration ~1.5 sec was applied to the sample for the purpose of emptying the carrier in depletion region. Upon which pulses with a test frequency of 10 kHz and 100 meV rms was employed to record its small signal diode capacitance.

Figure 1(a) and 1(b) show the transient capacitance of the undoped GaN measured at room temperature at different time *t* after the illumination was switched off. As can be seen in Figs. 1(a) and 1(b), for each measurement when the square trigger was applied, the small signal capacitance tends to increase exponentially at the beginning and saturate to a steady value within the duration of ~ 0.2 sec, irrespective of the measurements at different time. The initial uprising portion observed here is believed to be attributed primarily to the point defects associated with 0.60 eV below conduction band because of the characteristics of same time constant and defect concentration, as revealed by the DLTS measurements. Nevertheless, this particular trap is by no means the reason responsible for the long term photocapacitance behavior, due to its fast dynamic response in nature. It is the other defects that cause the effect observed in our GaN film.

More clear picture can be observed in Fig. 2, where the steady values of photocapacitance, $C_{ss}(t)$, against different measurement time is illustrated. It is very interesting to note that the $C_{ss}(t)$ is found to decrease logarithmically as a function of time with values changed from 113 pF at 5 min. to 107 pF at 12 hours after the switch-off of the light. Such a variation can be expressed approximately as

$$\Delta C_{ss}(t) \propto -\log(t).$$

Similar phenomenon has also been observed in a plastically deformed n-type GaAs [3] reported by Nakata and Ninomiya, in which logarithmic-type decay behavior was observed in term of photoconductivity in their GaAs

film. They ascribe this special feature to the carrier recombination involved with the dislocations presented in the epilayer. We believe this is also the very case occurred in our heteroepitaxial GaN film. The mechanism corresponding to the long-term photocapacitance behavour of GaN film can be described well by barrier-limited recombination model and is expressed as follows:

During this experiment, GaN sample was under light illumination at the beginning, generating a large number of excess holes in the valence band as shown in Fig. 3 (a). Owing to the characteristic of short minority carrier lifetime (~6.5 ns) in n-GaN, the excited holes will soon fall into the dislocations. At the end of photopumping most of traps along dislocation lines are conceivably filled with holes and become neutrally charged (Fig. 3 (b)). Later on, when the light was turned off, the trapped holes remains at the dislocations until recombination with electrons from the conduction band (Fig. 3 (c)). It is worth to mention that the capture of electrons by dislocations discussed here proceeds rather slowly as compared to that of holes. This is because that these dislocation traps in principle act as repulsive Coulomb scattering centers for electrons nearby. Unlike the filling of holes, a cylindrical potential barrier is presented between the free electrons and dislocation lines due to the nature of negative charge property of core dislocation. By using the barrier-limited recombination model, and the fitting results from Fig. 2, we found that the calculated logarithmic time constant and averaged electron capture cross section of the dislocation lines are ~ 34.5 sec and $<2.89\times10^{-27}$ cm^2, quite in agreement with the hypothetical repulsive Coulomb-force interaction.

In summary, we have employed the photocapacitance measurement to examine the physical properties of GaN Schottky diode made from the undoped epilayer grown by metalorganic vapor phase epitaxy. The resulted transient capacitance spectrum shows that the diode exhibits a characteristic of long-term logarithmic-type decaying behavior, which, we believe, is correlated closely to the linear arranged traps close to the core of the threading edge dislocations.

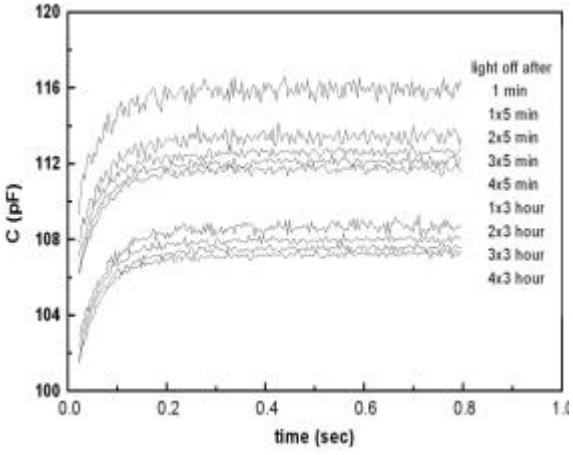

FIG. 1

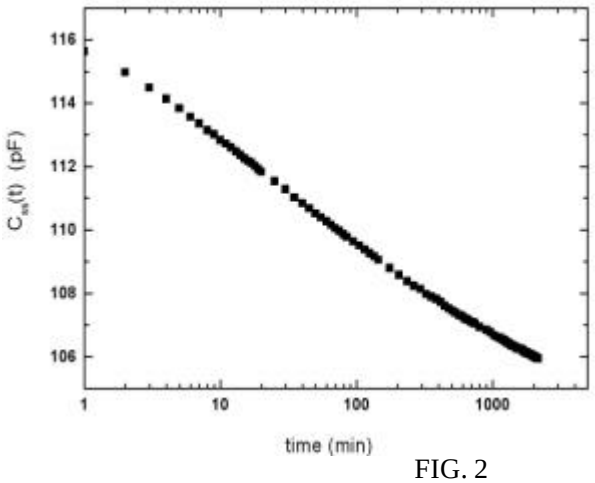

FIG. 2

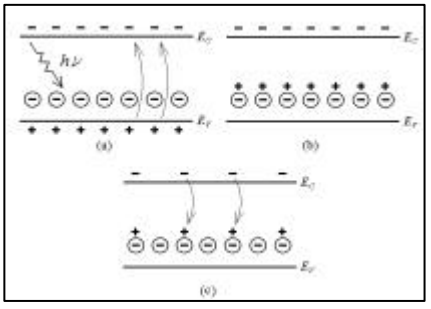

FIG. 3

[1] S.Yoshida, J. Suzuki, J. Appl. Phys. **84**, 2940 (1998).

[2] H. M. Chung, W. C. Chuang, Y. C. Pan, C. C. Tsai, M. C. Lee, W. H. Chen, W. K. Chen, C. I. Chiang, C. H. Lin, and H. Chang, Appl. Phys. Lett. **76**, 897 (2000).

[3] H. Nakata and T. Ninomiya, J. Phys. Soc. Jpn. **47**,1912(1979).